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ABSTRACT

In the "Austrian" tradition of stationary technology the lower rate of interest of a wealthier economy would always lengthen the time span of capitalist production and raise net national product. The paper examines how much of the Austrian tradition will survive the introduction of embodied technological progress. The lengthening time span will not survive. But with shorter useful life of its equipment the wealthier economy will at all times be operating at an average practice closer to best practice and still be enjoying a larger net national product.

BÖHM-BAWERK CENTENARY, II

TIME AND INTEREST: THE UN-AUSTRIAN CASE OF TECHNOLOGICAL PROGRESS

Hans Brems*

I. INTRODUCTION

1. The Austrian Time-Interest Relationship

Our Austrian heritage related the length of the time span of capitalist production to the rate of interest. In Böhm-Bawerk's (1889) case of circulating capital that time span was the period of production. In the Åkerman-Wicksell [1923, (1934)] case of fixed capital the time span was the useful life of durable producers' goods. The two cases were similar: a lower rate of interest would always lengthen the time span of capitalist production. Blitz (1958) and Kleiman-Ophir (1966) referred to and agreed with the Åkerman-Wicksell result.

2. The Time-Interest Relationship Occasionally Reversed: Reswitching

Reswitching attracted wide attention after 1960 but, as Velupillai (1975) has pointed out, was noticed already by Fisher (1907: 352-353). Reswitching refers to the possibility that a time structure of production might be optimal at a high rate of interest, inoptimal at a medium rate of interest, and once again optimal at a low rate of interest. Champernowne, Morishima, and Joan Robinson called reswitching "anomalous," "perverse," or a "curiosum."

Samuelson (1966: 571-574) summarized the debate by first examining the assumptions under which reswitching could not occur. In the case of circulating capital it could not occur as long as labor was employed uniformly throughout the period of production. In the case of fixed capital it could not occur as long as physical output was produced uniformly throughout the useful life of the durable producers' good. Next Samuelson relaxed both assumptions and found reswitching equally possible in both cases. Perhaps equally possible but hardly equally plausible: ripening wine or growing timber typically may not employ labor uniformly throughout their period of production. But durable producers' goods are typically designed to produce their physical output uniformly. Barna (1961: 80) observed that "indeed for important classes of assets efficiency does not decline [with age] at all." Domar (1961: 98) quoted Leontief to the same effect.

3. Embodied Technological Progress

Embodied technological progress as a source of growth was first examined by Johansen (1959), Solow (1960), (1962), and Massell (1962). Perhaps because of their growth focus, none of the three writers related embodied technological progress to the rate of interest. Perhaps because of the absence[1] of any interest focus, embodied technological progress remained unrelated to reswitching.

Our own focus is on the time-interest relationship. Our clue will be a wage-price squeeze inherent in embodied technological progress: let the money wage rate be inflating at the rate g but let the competitive price of output reflect latest technology hence be inflating at the general rate of inflation g <u>minus</u> the rate of technological progress q. Since once installed producers' goods cannot be altered, such failure of the price of their output to inflate as rapidly as the money wage rate paid to operate them will be tempting their owner to replace them. The older the producers' goods the more irresistible the temptation to replace them. Let technological progress be two percent per annum and useful life 28 years. Then a replacing unit will be 1.75 times as efficient as the retired one. Exactly when should the entrepreneur give in to the temptation? Obviously not too frequently, or the capital cost of such throw-away extravagance would become too high. But not too infrequently either, or the wage-price squeeze would destroy the firm. Such matters will be decided by the market mechanism, i.e., by the rate of interest.

4. The Time-Interest Relationship Permanently Reversed?

Because embodied technological progress was related to neither the rate of interest nor reswitching, a more fundamental--and more plausible--"perversity" escaped notice: rule out reswitching by assuming uniformity of output and operating-labor input throughout useful life. Instead of an occasional reswitching point at which the slope of the time-interest relationship would reverse itself might the slope be permanently reversed? Might in other words a lower rate of interest <u>always</u> shorten rather than lengthen useful life? Indeed it might, and we shall now see how.

Let us build the simplest possible model which will determine optimal useful life of durable producers' goods under embodied technological progress. There will be only two goods, a consumers' good and a durable producers' good, and only two kinds of labor, construction labor and operating labor. With its embodied technological progress our economy cannot be stationary, but at least we can make such progress its only source of growth: its available labor force and physical capital stock will remain stationary. Getting no larger numerically, physical capital stock will be getting better: replacements will embody technological progress. Like Solow, Tobin, von Weizsäcker, and Yaari (1966) we shall make no attempt to "explain the advance of technical knowledge; it is autonomous, requires no productive resources, and cannot be accelerated or retarded."

We use the following notation.

5. Variables

$C \equiv$ aggregate physical consumption

$I \equiv$ aggregate physical gross investment

$J \equiv$ present net worth of an endless succession of investments

L $\equiv$ labor employed

P $\equiv$ price of consumers' goods

p $\equiv$ price of producers' goods

S $\equiv$ aggregate physical capital stock of producers' goods

u $\equiv$ useful life of producers' goods

X $\equiv$ physical output of consumers' goods per annum per producers' good

6. Parameters

a_1 $\equiv$ labor absorbed in constructing one physical unit of producers' goods

a_2 $\equiv$ labor absorbed per annum in operating one physical unit of producers' goods

F $\equiv$ available labor force

g $\equiv$ rate of inflation

q $\equiv$ rate of technological progress

r $\equiv$ nominal rate of interest

ρ $\equiv$ real rate of interest $\equiv$ nominal rate of interest minus rate of inflation

w $\equiv$ money wage rate

II. FIRM EQUILIBRIUM: OPTIMIZE USEFUL LIFE WITH RESPECT TO INTEREST RATE

1. An Endless Succession of Vintages of Durable Producers' Goods

Let an entrepreneur plan an endless succession of vintages of durable producers' goods: every uth year a retired producers' good is replaced by a new one embodying latest technology.

Define present net worth of such an endless succession as present worth of all its future revenue minus present worth of all its future construction labor minus present worth of all its future operating labor.

2. Present Worth of All Future Revenue

Since efficiency differs among vintages we must carefully distinguish between vintages. For each vintage v we adopt a point-input, flow-output scheme and assume physical output $X(v)$ of consumers' goods per annum per producers' good of vintage v to remain uniform throughout the useful life of that vintage. Such uniformity will rule out reswitching [Samuelson (1966)].

Let output sell at a price P reflecting latest technology hence inflating at the general rate of inflation minus the rate of technological progress q per annum:

$$P(t) = e^{(g - q)(t - v)}P(v) \tag{1}$$

Occurring continuously, then, revenue of vintage v during a small fraction dt of a year located at time t is $P(t)X(v)dt$. As seen from time v the present worth of that is $e^{-r(t - v)}P(t)X(v)dt$ or, with (1) inserted and the real rate of interest defined as $\rho \equiv r - g$, $e^{-(\rho + q)(t - v)}P(v)X(v)dt$. The present worth of all such future revenue throughout the useful life of vintage v is then the integral

$$\int_v^{v + u} e^{-(\rho + q)(t - v)}P(v)X(v)dt = \frac{1 - e^{-(\rho + q)u}}{\rho + q} P(v)X(v) \tag{2}$$

So much for vintage v. Later vintages will embody new technology: over the vintages X will be growing at the rate of technological progress q per annum:

$$X(t) = e^{q(t - v)}X(v) \tag{3}$$

Now consider the ith replacement installed at time $t = v + iu$. In (2) replace v by $v + iu$ and find the future worth as seen from time $t = v + iu$ of all revenue expected from the ith replacement throughout <u>its</u> useful life:

$$\frac{1 - e^{-(\rho + q)u}}{\rho + q} P(v + iu)X(v + iu) \tag{4}$$

Replacements always embody latest technology, so according to (3) physical output per annum of the ith replacement will be

$$X(v + iu) = e^{iqu}X(v) \tag{5}$$

and according to (1) price of its output will be

$$P(v + iu) = e^{(g - q)iu}P(v) \tag{6}$$

Multiply (5) by (6) and find revenue of the ith replacement

$$P(v + iu)X(v + iu) = e^{giu}P(v)X(v) \tag{7}$$

So over the vintages the failure of P to inflate at the full rate g per annum is made up for by an X(v) growing at the rate q of technological progress. Over the vintages, then, revenue is after all inflating at the full rate q per annum.

Now insert (7) into (4) and see the latter from iu years earlier by multiplying it by e^{-iru}, thus finding present worth as seen from time t = v of all revenue expected from the ith replacement over its useful life

$$\frac{1 - e^{-(\rho + q)u}}{\rho + q} e^{-\rho iu}P(v)X(v) \tag{8}$$

Finally write (8) successively for i = 0, 1, 2, ... Summing over vintages find the present worth of an endless succession of future revenues

$$\frac{1 - e^{-(\rho + q)u}}{\rho + q} (1 + e^{-\rho u} + e^{-2\rho u} + \ldots)P(v)X(v)$$

The parenthesis is an endless geometrical progression with first term 1, common ratio $e^{-\rho u}$, and sum $1/(1 - e^{-\rho u})$. As a result the present worth of the endless succession of future revenues will be

$$\frac{1 - e^{-(\rho + q)u}}{\rho + q} \frac{P(v)X(v)}{1 - e^{-\rho u}} \tag{9}$$

3. Present Worth of All Future Construction Labor

Let the length of the construction period of producers' goods be negligible. Let us be truly Ricardian and Wicksellian and assume their construction to require nothing else than labor. Let a_1 be the labor absorbed in constructing one physical unit of producers' goods, and let a_1 be a function of neither useful life nor vintage: simply let reliability of operation dictate a physical quality of producers' goods such that they become obsolescent before they wear out.

But let producers' goods be priced p and sold under pure competition and freedom of entry and exit. Then their price will equal their cost of production

$$p(t) = a_1 w(t) \tag{10}$$

Let the money wage rate be inflating at the rate g per annum:

$$w(t) = e^{g(t - v)} w(v) \tag{11}$$

Occurring every uth year, construction-labor cost is $a_1 w(t)$ whose present worth is $e^{-r(t - v)} a_1 w(t)$ or, with (11) inserted,

$$e^{-\rho(t - v)} a_1 w(v) \tag{12}$$

Write (12) successively for $t = v, v + u, v + 2u, \ldots$ Summing over vintages, find the present worth of an endless succession of future construction labor

$$(1 + e^{-\rho u} + e^{-2\rho u} + \ldots) a_1 w(v)$$

The parenthesis is an endless geometrical progression with first term 1, common ratio $e^{-\rho u}$, and sum $1/(1 - e^{-\rho u})$. As a result the present worth of the endless succession of future construction labor is

$$\frac{a_1 w(v)}{1 - e^{-\rho u}} \tag{13}$$

4. <u>Present Worth of All Future Operating Labor</u>

Throughout its useful life, but regardless of its vintage, let a_2 be labor absorbed uniformly per annum in operating one physical unit of producers' goods. Such uniformity will rule out reswitching [Samuelson (1966)].

Occurring continuously, then, operating labor cost during a small fraction dt of a year located at time t is $a_2 w(t)dt$. As seen from time v the present worth of that is $e^{-r(t - v)} a_2 w(t)dt$ or, with (11) inserted, $e^{-\rho(t - v)} a_2 w(v)dt$, and the present worth of all such future operating labor is

$$\int_v^\infty e^{-\rho(t - v)} a_2 w(v) dt = \frac{a_2 w(v)}{\rho} \tag{14}$$

5. Maximizing Present Net Worth of Endless Succession of Vintages

We defined present net worth of our endless succession of vintages as present worth (9) of its future revenue minus present worth (13) of its future construction labor minus present worth (14) of its future operating labor. Call that present net worth J(v), insert (9), (13), and (14), and find it to be

$$J(v) = \frac{1 - e^{-(\rho + q)u}}{\rho + q} \frac{P(v)X(v)}{1 - e^{-\rho u}} - \frac{a_1 w(v)}{1 - e^{-\rho u}} - \frac{a_2 w(v)}{\rho} \tag{15}$$

Finally differentiate present net worth J(v) with respect to useful life u treating the real rate of interest ρ and the rate of technological progress q, $a_1w(v)$, $a_2w(v)$, and P(v)X(v) as constants to the firm. In the derivative write $e^{-(\rho + q)u}$ as $e^{-\rho u}e^{-qu}$. Set the derivative equal to zero. Multiply both sides by $(\rho + q)(1 - e^{-\rho u})^2$, divide them by $e^{-\rho u}\rho P(v)X(v)$, let terms cancel, and find the first-order transcendental condition for a maximum $J(v)$:

$$\left(1 + \frac{1 - e^{-\rho u}}{\rho} q\right)e^{-qu} + (\rho + q)\frac{a_1 w(v)}{P(v)X(v)} - 1 = 0 \qquad (16)$$

Negative values of u would be meaningless: no life can be shorter than zero! As it turns out, only small, hence realistic, values of our parameters, $\rho > 0$, $q > 0$, $\rho + q \leq PX/(a_1 w)$ which is[2] about 1/4, will deliver meaningful roots of (16). For twelve such pairs (ρ, q) table I and figure 1 show such roots. For the realistic pair $\rho = 0.04$, $q = 0.02$ the table shows $u = 28.3$, a realistic value--see Maddison (1987: 664). Optimal useful life u is shown to be a rising function of the real rate of interest ρ--our un-Austrian result! The curvatures of our double-logarithmic figure 1 show the elasticity of u with respect to ρ to be rising with ρ.

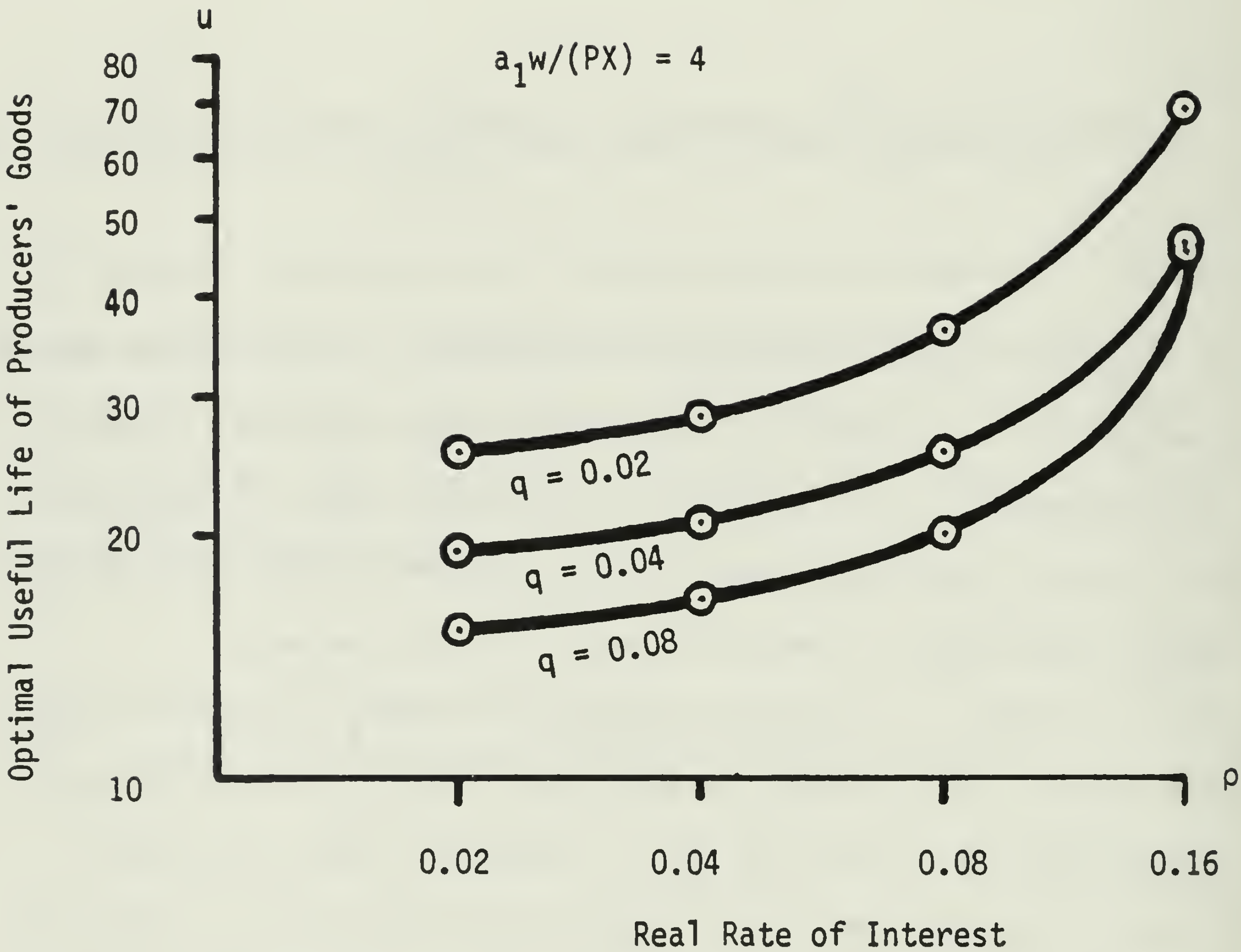
u
80
70
60
50
40
30
20
10
Optimal Useful Life of Producers' Goods
a1w/(PX) = 4
q = 0.02
q = 0.04
q = 0.08
ρ
0.02
0.04
0.08
0.16
Real Rate of Interest

Figure 1

TABLE I. ROOTS OF (16)

OPTIMAL USEFUL LIFE AS A FUNCTION OF REAL RATE OF INTEREST

Technological Progress q	Real Rate of Interest ρ 0.02	0.04	0.08	0.16
0.02	25.5	28.3	36.1	69.5
0.04	19.2	20.9	25.4	45.8
0.08	15.4	16.7	20.1	45.3

As Wicksell did, we shall now use our microeconomic time-interest relationship to build a macroeconomic equilibrium.

III. MACROECONOMIC EQUILIBRIUM: USEFUL LIFE AND NET NATIONAL PRODUCT

1. Full Employment

Labor absorbed in constructing one physical unit of producers' goods was a_1, and the aggregate physical output per annum of such goods was I. Consequently aggregate labor employed per annum in construction is

$$L_1 = a_1 I \tag{17}$$

Labor absorbed per annum in operating one physical unit of producers' goods was a_2, and the aggregate physical capital stock of such goods is S. Consequently aggregate labor employed per annum in operation is

$$L_2 = a_2 S \tag{18}$$

Let physical gross investment I be stationary. With useful life u physical aggregate capital stock S of producers' goods will then consist of u vintages, each of size I:

$$S = Iu \tag{19}$$

Let there be full employment:

$$F = L_1 + L_2 \tag{20}$$

Insert (17), (18), and (19) into (20) and find aggregate physical gross investment

$$I = \frac{F}{a_1 + a_2 u} \tag{21}$$

2. A Wealthier Versus a Less Wealthy Economy

A wealthier economy will have the lower real rate of interest, hence the shorter useful life of its producers' goods. How precisely does its greater wealth manifest itself?

One way it manifests itself is in a larger aggregate physical gross investment I: (21) is the larger the shorter useful life u--as we shall also see in Figure 2 below. But greater wealth does not manifest itself in a larger physical capital stock: insert (21) into (19), divide numerator and denominator alike by u, and find physical capital stock

$$S = \frac{F}{a_1/u + a_2} \qquad (22)$$

which is the smaller the shorter useful life u. But the smaller physical capital stock is a better one because it is younger. With such a smaller but younger physical capital stock will the physical net national product be growing faster? Will it be growing at higher level?

In money terms gross national product is CP + Ip. With our stationary physical capital stock net investment is zero, so physical net national product is simply C. What can we say about C?

Each producers' good of vintage t produced a physical output of consumers' goods X(t) per annum. All producers' goods I(t) of that vintage will then produce I(t)X(t) per annum. At time t = v, producers' goods of vintages from $t = v - u$ to $t = v$ will be in existence and produce an aggregate physical output of consumers' goods per annum found as the integral from $t = v - u$ to $t = v$ of $I(t)X(t)$ with respect to time. Since aggregate physical gross investment $I(t)$ was said to be stationary we may drop its time coordinate. Each existing vintage has a different $X(t)$, but in accordance with (3), over the vintages X was growing at the rate of technological progress q per annum. So our integral will be

$$C(v) = \int_{v-u}^{v} I(t)X(t)dt = \frac{1 - e^{-qu}}{q} IX(v) \tag{23}$$

Insert (21) into (23), rearrange, and express physical net national product $C(v)$ as a multiple of physical output $X(v)$ of consumers' goods per annum per producers' good of latest vintage:

$$\frac{C(v)}{X(v)} = \frac{1 - e^{-qu}}{q} \frac{F}{a_1 + a_2 u} \tag{24}$$

3. Will the Wealthier Economy be Growing Faster?

Our multiple (24) will help us see that the wealthier economy will be growing no faster than the less wealthy economy. Their common rates of inflation g and of technological progress q are stationary parameters. According to (7) and (11) the numerator and the denominator of the ratio $a_1w/(PX)$ in (16) were both growing at the rate g, so that ratio will remain stationary. As long as the nominal rate of interest, whatever its level, remains stationary the entire transcendental equation (16) and its root u, whatever their levels, will remain stationary. Available labor force F was also a stationary parameter, consequently the entire multiple (24), whatever its level, will remain stationary, and physical net national product C(v), whatever its level, will be growing at the same rate as X(v). According to (3) that rate is the common rate of technological progress q. As a result, with a smaller but younger physical capital stock the physical net national product C(v) of the wealthier economy will be growing no faster than the less wealthy one.

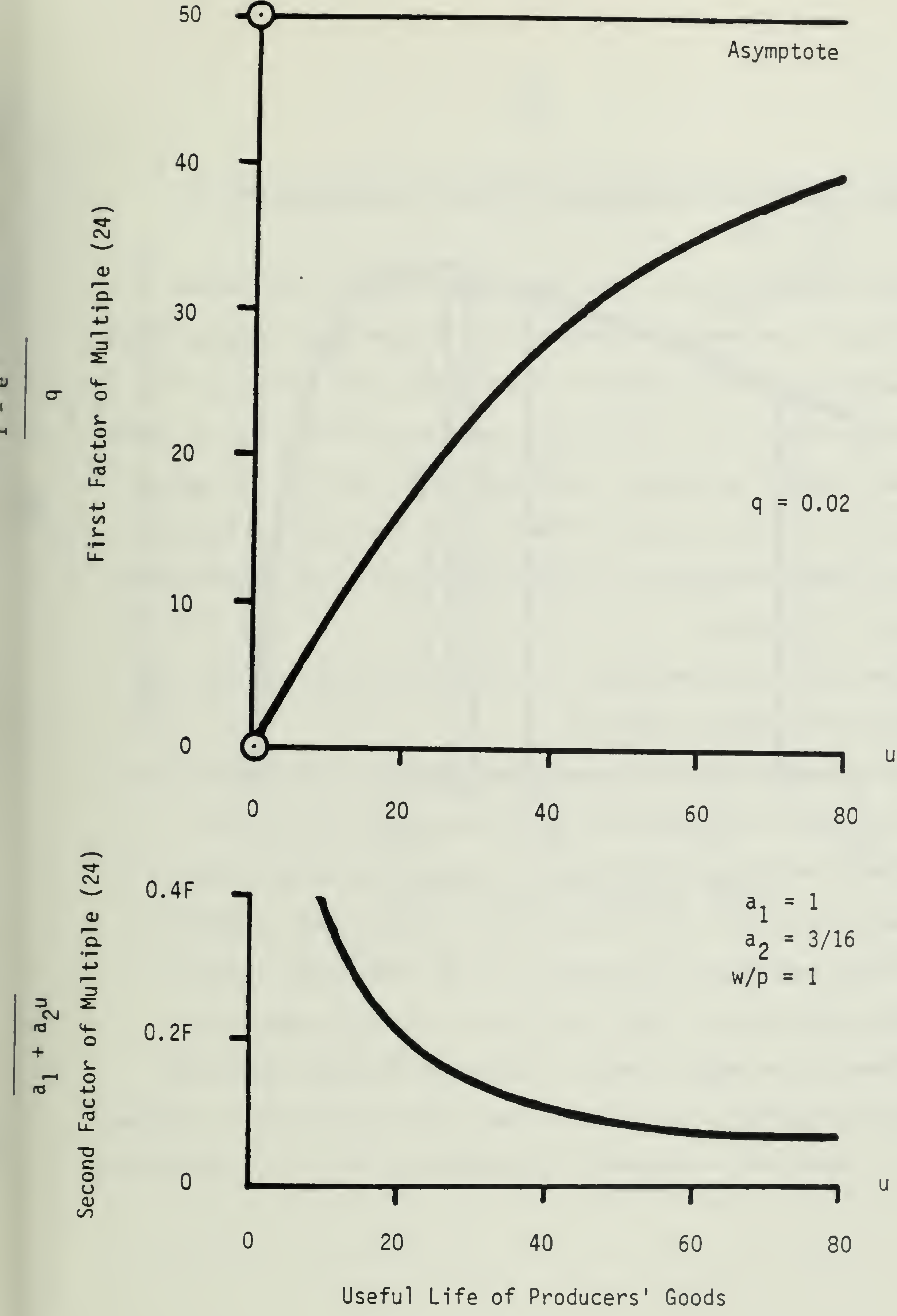
50
40
30
20
10
0
Asymptote
First Factor of Multiple (24)
q = 0.02
u
0
20
40
60
80
0.4F
0.2F
0
Second Factor of Multiple (24)
a1 + a2u
a1 = 1
a2 = 3/16
w/p = 1
u
0
20
40
60
80
Useful Life of Producers' Goods

Figure 2

4. Will the Wealthier Economy be Growing at a Higher Level?

Our multiple (24) will also help us see that at their common growth rate q the wealthier economy will be growing at a higher level. The multiple (24) is a product of two factors, both functions of u. The first factor is $(1 - e^{-qu})/q$, is shown in the upper half of figure 2, and is always the smaller the shorter useful life u. The second factor is $I = F/(a_1 + a_2u)$, is shown[3] in the lower half of figure 2, and is always the larger the shorter useful life u--as we already saw in sec. III, 2 above.

What will be the net effect of such opposed tendencies upon the multiple (24) shown in figure 3?

At any given rate q of technological progress the multiple (24) will at first be the larger the shorter the useful life u but eventually decline with shortening u. In which range will the economy find itself? For a given rate of technological progress q = 0.02 and real rates of interest ρ = 0.16, 0.08, 0.04, or 0.02, optimum useful lives u = 69.5, 36.1, 28.3, or 25.5, respectively are found in the range in which the multiple (24) gets larger the shorter the useful life. So at a given rate of technological progress q, at a given X(v), with useful life optimized, and with a smaller but

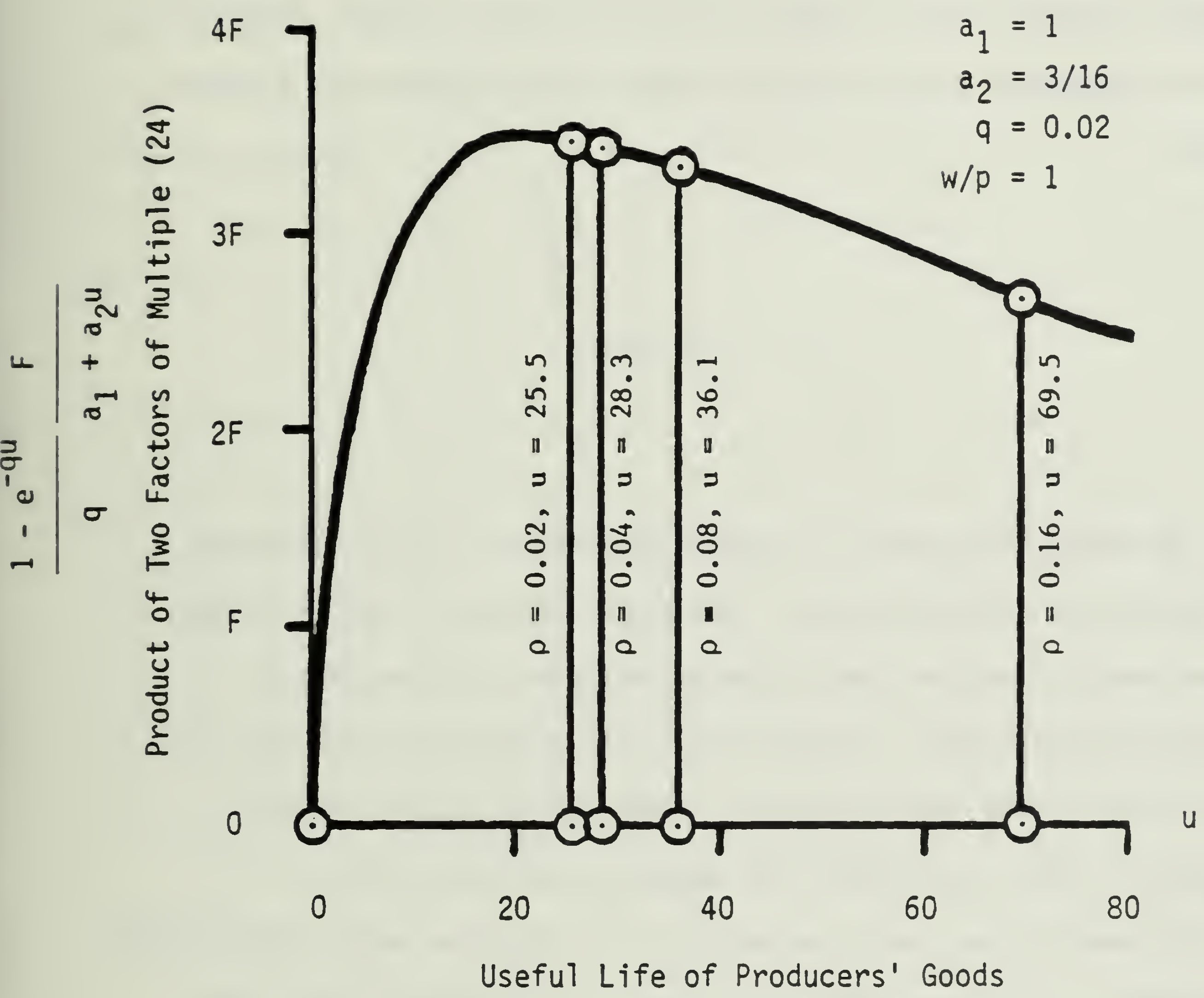
$a_1 = 1$
$a_2 = 3/16$
$q = 0.02$
$w/p = 1$
4F
3F
2F
F
0
$\frac{1 - e^{-qu}}{q} \frac{F}{a_1 + a_2 u}$
Product of Two Factors of Multiple (24)
$\rho = 0.02$, $u = 25.5$
$\rho = 0.04$, $u = 28.3$
$\rho = 0.08$, $u = 36.1$
$\rho = 0.16$, $u = 69.5$
u
0
20
40
60
80
Useful Life of Producers' Goods

Figure 3

younger physical capital stock the physical net national product C(v) of the wealthier economy will be larger, i.e., growing at a higher level.

IV. CONCLUSION

The Böhm-Bawerk case of circulating capital and the Åkerman-Wicksell case of fixed capital had three things in common. First, a lower rate of interest would always lengthen the time span of capitalist production. Second, with its lengthening time span, the wealthier economy would enjoy the larger physical net national product. Third, technology was assumed to be stationary.

How much of our Austrian heritage will survive under technological progress? As we have shown, the idea of a lengthening time span induced by a lower rate of interest will not survive: shorter, not longer, useful lives would be induced!

But, as we have also shown, the idea of a wealthier economy enjoying a larger physical net national product will survive: with a smaller but younger physical capital stock the physical net national product will be growing no faster but will indeed be growing at a higher level. The reason it will would have been new to Böhm-Bawerk and Wicksell: with its throw-away extravagance the wealthier economy will at all times be operating at an "average" practice closer to "best" practice.

FOOTNOTES

*To solve our transcendental equation (16) for small values of its parameters ρ and q a modification of the Newton-Raphson method was desirable. For such modification and for computing the twelve solutions of (16) the author is indebted to Dan Connors of the Coordinated Science Laboratory of the University of Illinois. To Larry Samuelson, visiting at the University of Illinois, the author is indebted for careful reading of an earlier draft.

[1] Solow, Tobin, von Weizsäcker, and Yaari (1966: 87, 102) did see the "un-Austrian" fact that a growth path with a longer useful life would be the one with a higher rate of interest but offered no explicit optimization of useful life with respect to the rate of interest.

[2]In (16) apply (10) to see that $a_1 w = p$, so $a_1 w/(PX)$ is price of a producers' good divided by the value of its annual output or simply the capital coefficient of the consumers' goods industry. Let it equal, say, 4, then its reciprocal is 1/4, and our restriction is $\rho + q \leq 1/4$.

[3]How did we pick the values $a_1 = 1$, $a_2 = 3/16$, and $w/p = 1$? First multiply numerator and denominator alike of (21) by w/p. According to (10) the first term of the denominator is $a_1 w/p = 1$. According to (18), in the last term of of the denominator $a_2 w/p = L_2 w/(pS)$. If in the consumers' goods industry labor's share is, say, 3/4 and the capital coefficient is, say, 4, then $L_2 w/(pS) = 3/16$. Finally choose units of labor and producers' goods such that $w/p = 1$.

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